Original Research Article

MEASUREMENT AND PREDICTION OF WORKPLACE EXPOSURE TO SOLAR ULTRAVIOLET RADIATION IN MAKURDI, BENUE STATE, NIGERIA

ABSTRACT

Aims: To measure and predict the workplace exposure to solar ultraviolet radiation in Makurdi, Benue State, Nigeria.
Study design: Experimental design through area monitoring method and Newton divided interpolation difference method.
Place and Duration of Study: Makurdi Metropolis, Benue State and Department of Physics, Nasarawa State University Keffi, Nigeria, between April and June 2021.
Methodology: Digital broad band meter was used to measure UV irradiance at SRS junction (Traffic light) and Kanshio (construction site) at hourly intervals from 10:00am- 4:00pm. The exposure results were used to derive a predicting function using the Newton Divided Difference Interpolation method and were plotted into MATLAB to generate the predicted results. Also, the UV index was also calculated.
Results: The mean irradiant values were 179.1J/m^2 and 173.53J/m^2 with erythema effective irradiances 227.3J/m^2 and 205J/m^2 which is 1.14 and 1.03 minimum erythema doses (MED)/hr, while the predicted mean values were 179.1±0.025J/m^2 and 172.8±0.004J/m^2 for the traffic wardens and construction site workers respectively. The mean values were higher than the ICNIRP recommended safety limit of 30J/m^2 for occupational exposure and MED for skin type I was exceeded by a factor of 1. The calculated UV index was 8 for construction site and 9 for traffic light wardens.
Conclusion: High level of accuracy of the prediction model implies that it can be used for prediction of SUV radiation. However, high mean irradiant values with high UV index indicates high risk of harm from unprotected sun exposure. Therefore, use of sun protective clothing is recommended and reduce time in the sun especially between 1:00pm and 2:00pm to prevent over exposure that will lead to serious harmful effects.

Keywords: *Irradiance; UV radiation; occupation exposure; minimum erythema doses; prediction function; Newton divided interpolation*

1. INTRODUCTION

Solar Ultraviolet Radiation (SUVR) is part of the non-ionizing electromagnetic radiation spectrum emitted by the sun that has influence on major processes in the biosphere [1, 2]. Ultraviolet radiation (UV) is divided into three bands of wavelengths which are UVA (320-400nm), UVB (290-320nm) and UVC (200-290nm) [3]. A major portion of the UV-A and about 10% of UV-B radiation reaches the earth's surface from the sum while UV-C is totally absorbed by the atmospheric ozone, water vapour and gasses [4, 2, 5].

Solar UV radiation has beneficial effects to human health and Agriculture. However, over exposure to UV radiation plays a major role in the development of Photo-conjunctivitis, Skin cancers, Pterygiun, Cortical Cataract, Photo-ageing, Carcinoma of cornea, immune depression in humans, plant susceptibility to diseases and great threat to crops and ecological system [6, 7, 2]. Despite the numerous effects of UVR, its measurement and prediction has received negligible attention and the observational data available are scanty and few [8, 2].

According to Fleischamnn, [9] quantification of the amount of radiation a living being receives is paramount in examining the effects of solar UV radiation on living beings as well it predictability, hence, this research. This study seeks to predict the Solar UV radiation the amount of SUVR an outdoor worker receives at given intervals so as to complement the National and international UVR protection programs such as WHO-INTERSUN on global UV project and in so doing contribute to the baseline data that would enable a successful UV Index forecast especially in the study location.

2. MATERIALS AND METHODS

2.1 Materials

The materials that were utilized for the purpose of this research includes TM-206 digital UV broadband meter, rubber human manikin, UV/VIS spectrophotometer, polymer polysolphone dosimeters, and Twelve-channel GPS.

2.2 Methods

2.2.1 Study Area

This study was carried out in Makurdi town which is sited between latitude 7°38'N - 7°50'N, and longitude 8°24'E and 8°38'E. It is situated in the Benue valley in the North Central region of Nigeria. River Benue which is the second largest river in the country cuts across Makurdi town and divides it into the north and south banks. The population of Makurdi is around 500,797 [10]. The main occupation of the inhabitants of Makurdi town is largely of people who engage in civil service duties, commercial activities and agrarian peasantry. Makurdi town doubles as the headquarters of Makurdi Local Government Area as well as the capital of Benue State.

2.2.2 Sample Points/ Locations

The simple random sampling technique was used to select two locations where the area monitoring survey was carried out and the GPS readings for the study locations where data was taken for this study is presented in Table 1.

Table 1. GPS Locations at various Study sites

S/N	Location	Location Code	Longitude	Latitude	Angle of Elevation
1	Kanshio (Construction Site)	CW	07040.8709'	008032.2369'	118m
2	SRS Junction (Traffic)	TW	07045.6870'	00804729'	138m

2.2.3 Determination of Effective Dose using Newton Divided Method

In order to have idea about the UV exposure of outdoor workers in between the hours which data was collected, predicting formulas were obtained using Newton Divided Interpolation (NDDI). Given a function y = f(x), which may be a set of data points between y_n and x_n, the process of finding the value of y corresponding to any value of $x = x_i$ between x_0 and x_n is referred to as interpolation. Thus, Interpolation is the technique of estimating the value of a function for any intermediate value of the independent variable [11]. Polynomial functions are preferred to other functions for interpolating because many operations such as determination of roots, differentiation and integration can be performed more easily [12].

To construct Newton divided difference interpolating polynomials, let the nodes or arguments be defined by $x_k = x_0, x_1, x_2, \ldots, x_n$ and the unknown function $f(x_k)$. The coefficients of Newton divided difference polynomial as described in Burden and Fairs [13] are obtained from Table 2.

Once the coefficients are obtained for Table 2, for each k = 0, 1, 2,…, n, Newton Divided Difference Polynomial is given by;

$$P_n(x) = f[x_0] + \sum_{k=1}^{n} f[x_0 x_1, \ldots, x_k](x - x_0) \ldots (x - x_{k-1}) \qquad (1)$$

Equation (1) was applied to get the required predicting function at the various study sites. The generated equation is thereafter plotted into Matlab to obtain accurate values.

2.2.4 Method of Comparing Data Point with Prediction Function

Data points are measured irradiance values which were used to compare with the generated values from the prediction function. The prediction function are values obtained by the using Newton Divided Interpolation Difference plotted in Matlab.

2.6 UV Index Calculation Method

The UV Index for the two sites were calculated following the relationship given by Downs *et al.* [14] as follows:

$$I_{UV} = \frac{E_{ery}}{25} \qquad (2)$$

Where E_{ery} is the erythema effective UV Irradiance.

Table 2. Creation of Mathematical Model to Determine Dose [13]

X	$f(x)$	First Divided Difference	Second Divided Difference	Third Divided Difference
x_0	$f[x_0]$			
		$f[x_0,x_1] = \frac{f[x_1]-f[x_0]}{x_1 - x_0}$		
x_1	$f[x_1]$		$f[x_0,x_1,x_2] = \frac{f[x_1,x_2]-f[x_0,x_1]}{x_2 - x_0}$	
		$f[x_1,x_2] = \frac{f[x_2]-f[x_1]}{x_2 - x_1}$		$f[x_0,x_1,x_2,x_3] = \frac{f[x_1,x_2,x_3]-f[x_o,x_1,x_2]}{x_3 - x_0}$
x_2	$f[x_2]$		$f[x_1,x_2,x_3] = \frac{f[x_2,x_3]-f[x_1,x_2]}{x_3 - x_1}$	
		$f[x_2,x_3] = \frac{f[x_3]-f[x_2]}{x_3 - x_2}$		$f[x_1,x_2,x_3x_4] = \frac{f[x_2,x_3,x_4]-f[x_1,x_2,x_3]}{x_4 - x_1}$
x_3	$f[x_3]$		$f[x_2,x_3,x_4] = \frac{f[x_3,x_4]-f[x_2,x_3]}{x_4 - x_2}$	
		$f[x_3,x_4] = \frac{f[x_4]-f[x_3]}{x_4 - x_3}$		$f[x_2,x_3,x_4,x_5] = \frac{f[x_3,x_4,x_5]-f[x_2,x_3,x_4]}{x_5 - x_2}$
x_4	$f[x_4]$		$f[x_3,x_4,x_5] = \frac{f[x_4,x_5]-f[x_3,x_4]}{x_5 - x_3}$	
		$f[x_4,x_5] = \frac{f[x_5]-f[,x_4]}{x_5 - x_4}$		
x_5	$f[x_5]$			

3. RESULTS

3.1 Hourly UV Exposure

The result of hourly UV exposure of various occupations at their respective sites that were measured from 10:00am to 4:00pm on 14 – 15 March, 2021 using the UV broadband meter is presented in Table 3.

Table 3. Hourly UV Exposure of Various Occupations

		Exposure (W/m^2)			
Occupation	**Time**	**R1**	**R2**	**R3**	**Mean**
TW	10am	113.9	115.8	116.9	115.5
	11am	189.1	181.0	161.3	177.3
	12noon	190.3	189.2	189.3	189.6
	1pm	227.0	228.0	227.0	227.3
	2pm	214.0	213.0	215.0	214.0
	3pm	177.9	175.8	172.5	175.4
	4pm	159.6	153.2	151.1	154.6
CW	10am	123.7	130.3	129.0	127.7
	11am	175.0	177.7	180.7	177.8
	12noon	180.7	188.3	180.7	183.2
	1pm	198.0	199.3	190.7	196.0
	2pm	207.0	200.0	209.0	205.3
	3pm	178.4	177.3	180.0	178.6
	4pm	137.7	146.0	140.5	141.4

Key: CW = construction workers, TW = traffic workers, R = reading.

Table 3 constitutes the results for traffic light workers and construction site workers at SRS junction and Kanshio. It can be seen that the solar irradiance indicates the highest irradiance of 227.3W/m^2 at 1pm for traffic light workers and 205.3W/m^2 at 2pm for construction site workers respectively. The lowest irradiance was recorded at 10am with 115.5W/m^2, 127.7W/m^2 for traffic light workers and construction site workers respectively. By comparison, it is worthy of note that irradiance highest values were obtained within the intervals of 12 to 2pm and this is as a result of high solar intensity witness at these hours within the metropolis.

3.2 Prediction Model using Newton Divided Difference

The result of the UV irradiance from Table 3 was used to generate the prediction functions for the two sites using the Newton divided difference template in Table 2, the results are presented as shown in Table 4.

Table 4. Generated Newton divided difference

n	x_n	$f[x_n]$	$f[x_{n-1}, x_n]$	$f[x_{n-2}, x_{n-1}, x_n]$	$f[x_{n-3}, x_{n-2}, x_{n-1}, x_n]$	$f[x_{n-4} \dots x_n]$	$f[x_{n-5} \dots x_n]$	$f[x_{n-6} \dots x_n]$
0	10	115.5						
			61.8					
1	11	177.3		-24.75				
			12.3		12.483333333333343			
2	12	189.6		12.70		-6.304166666666672		
			37.7		-12.7333333333343		2.11166666666669	
3	13	227.3		-25.50		4.254166666666671		-0.4695833333333334
			-13.3		4.283333333333343		-0.7058333333333335	
4	14	214.0		-12.65		0.7249999999999997		
			-38.6		7.183333333333327			
5	15	175.4		8.90				
			-20.8					
6	16	154.6						

In order to obtain a predicting equation, we apply the results from Table 4 into the equation (1) as follows:

$$P_n(x) = f[x_0] + \sum_{k=1}^{n} f[x_0 x_1, \dots, x_k](x - x_0) \dots (x - x_{k-1})$$

We obtain:

$$P_1 = 115.5 + 61.8(x-10) - 24.75(x-10)(x-11) + 12.483333333333343(x-10)(x-11)(x-12) - 6.304166666666672(x-10)(x-11)(x-12)(x-13) + 2.111666666666669(x-10)(x-11)(x-12)(x-13)(x-14) - 0.469583333333334(x-10)(x-11)(x-12)(x-13)(x-14)(x-15) \quad (3)$$

Applying this to maple and factorizing gives:

$$P_1 = -2.097403989 * 10^6 x^2 + 21477.54790x^3 - 1229.781250x^4 + 37.33541664x^5 - 0.469583333x^6 - 2.328580997 * 10^6 + 1.085904265 * 10^6 x \quad (4)$$

Equation (4) is reconstructed as follows:

P_1 = 21470.37292*x.^3-1229.481250*x.^4+37.33041667*x.^5-.4695833333*x.^6-2.327379800*10^6-2.096548991*10^5*x.^2+1.085396647*10^6*x (5)

Equation (5) is the desired predicting equation which was used in Matlab in generating the predicted function for the Traffic Workers.

Similarly, the same procedure was followed to obtain the predicting equations and subsequently plotted in Matlab to generate predicted function for Construction Workers.

Thus the predicting equation is for the construction workers is giving as;

P_2 = 0.645138889*x^6-50.33875001*x^5+1629.136806*x^4-27990.56459*x^3+2.692531181*10^5*x^2-1.374802497*10^6*x+2.910798600*10^6 (6)

The predicted values for Traffic and Construction Workers are as presented in Table 5.

3.3 Comparison of Data Points with Predicted Functions

The Table 5 presents the result of data points which is the average of the measured irradiance and the prediction functions which were obtained from equations 5 and 6 by varying x which represents time interval between which data were measured i.e. 10:00 hours to 16:00 hours. From the results, errors were calculated for each measured data with prediction function as presented in Table 5.

Table 5. Predicted irradiance for traffic light and construction sites workers

Occupation	Time (Hours)	Data Points (W/m^2)	Prediction Function (W/m^2)	Error
TW4	10.000	115.5000	115.5137	0.0137
	11.000	177.3000	177.3168	0.0168
	12.000	189.6000	189.6203	0.0203
	13.000	227.3000	227.3243	0.0243
	14.000	214.0000	214.0289	0.0289
	15.000	175.4000	175.4342	0.0342
	16.000	154.6000	154.6401	0.0401
CW4	10.000	127.7000	127.6985	0.0015
	11.000	177.8000	177.7980	0.0020
	12.000	188.2000	183.1973	0.0027
	13.000	196.0000	195.9966	0.0034
	14.000	205.0000	204.9957	0.0043
	15.000	178.6000	178.5947	0.0053
	16.000	141.4000	141.3935	0.0065

Key: TW4 = traffic workers, CW4 = construction workers.

The results of traffic light (SRS Junction) indicates that at 10:00 hours, 115.5137W/m^2 was recorded as against the data point of 115.5W/m^2 with error 0.0137W/m^2. Similarly, at 11:00 hours, 177.3168W/m^2 value was obtained against the data point of 177.3W/m^2 which indicate a minimal error of 0.0168W/m^2 from the prediction function. Furthermore, at 12:00 hours to 16:00 hours, the following values were obtained from the prediction; 189.6203W/m^2, 227.3243W/m^2, 214.0289W/m^2, 175.4342W/m^2 and 154.6401W/m^2 against the data point values of 189.6W/m^2, 227.3W/m^2, 214.0W/m^2, 175.4W/m^2 and 154.6W/m^2 respectively which implies the corresponding errors of 0.0203W/m^2, 0.0243W/m^2, 0.0289W/m^2, 0.0342W/m^2 and 0.0401W/m^2 respectively.

Furthermore, from the construction site (Kanshio), the result reviewed that at 10:00 hours, 127.6985W/m^2 with a corresponding error of 0.0015W/m^2 against data point value of 127.7W/m^2. Likewise, 177.7980W/m^2 at 11:00 hours with an error of 0.0020W/m^2 against the data point of 177.8W/m^2. Also, at 12:00 hours, 183.1978W/m^2 was recorded with an error of 0.0027W/m^2 against 183.2W/m^2 data point value. The results for 13:00 hours to 16:00 hours were; 195.9966W/m^2, 204.9957W/m^2, 178.5947W/m^2 and 141.3935W/m^2 respectively with the corresponding errors of 0.0034W/m^2, 0.0043W/m^2, 0.0053W/m^2 and 0.0065W/m^2 respectively against the corresponding data point values of 196.0W/m^2, 205.0W/m^2, 178.6W/m^2 and 141.4W/m^2 respectively.

Graph of the predicted irradiance values against the data points for traffic light workers and construction site workers in dry season are presented in Fig. 1 and 2.

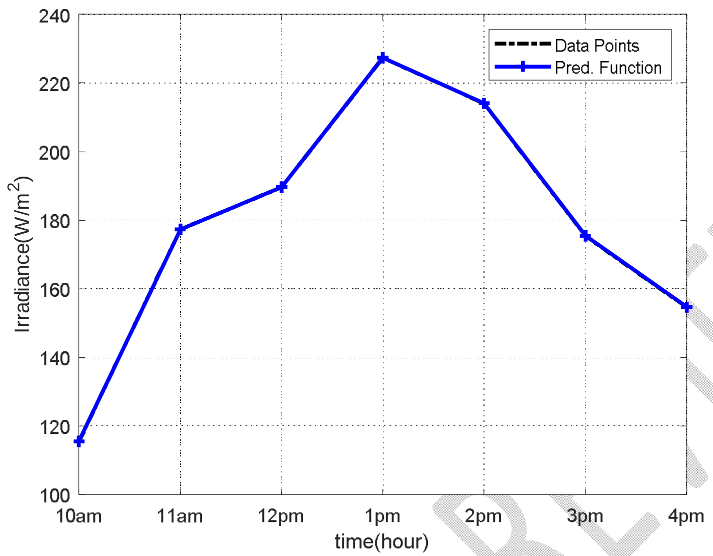

Fig. 1. Graph of predicted values with data points for traffic light workers (Dry Season)

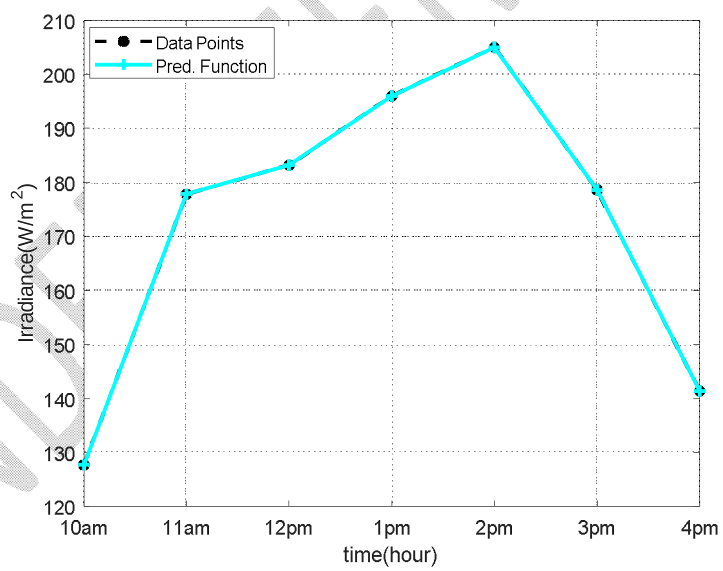

Fig. 2. Graph of predicted values with data points for construction site workers (Dry Season)

3.4 Calculated UV Index

The UVI for the study locations at the peak hours of this research duration were calculated from the tabulated values of UV Irradiance in Table 3, using equation (2). The values of UV Index obtained are presented in Table 6. Viz:

$I_{uv} = \frac{E_{ery}}{25}$

For TW

$I_{uv} = \frac{E_{ery}}{25} = \frac{227.3}{25} = 9$

For CW

$I_{uv} = \frac{E_{ery}}{25} = \frac{205}{25} = 8$

Table 6. Calculated UV Index, Description and Recommendation for Protection

S/N	Location	Calculated UV Index	Description	Media Graphics Colour	Recommendation for Protection
1	TW	9	Very high risk of harm from unprotected sun exposure	Purple	Wear sunglasses and use sunscreen having SPF 15 or higher, cover the body with sun protective clothing and a wide-brim hat, and reduce time in the sun from two hours before to three hours after solar noon (roughly 11:00 am to 4 PM during dry season that observe daylight saving time. Extra care should be taken as skin can burn easily.
2	CW	8	Very high risk of harm from unprotected sun exposure	Reddish	Wear sunglasses and use sunscreen having SPF 15 or higher, cover the body with sun protective clothing and a wide-brim hat, and reduce time in the sun from two hours before to three hours after solar noon (roughly 11:00 am to 4 PM during dry season that observe daylight saving time.

Key: TW = Traffic light workers and CW = construction site workers.

From Table 6 the calculated UV Index for TW and CW are 9 and 8 represented by the media graphic colours purple and reddish respectively. This indicates high risk of harm from unprotected sun exposure in both sites. It is therefore recommended that people working outdoor in these two sites should wear sunglasses and use sunscreen having SPF 15 or higher, cover the body with sun protective clothing and a wide-brim hat, and reduce time in the sun within solar peak hours during dry season that observe daylight saving time. Extra care should also be taken as skin can burn easily.

4. DISCUSSION

The measurement and prediction of workplace exposure to solar ultraviolet radiation in Makurdi, Benue State, Nigeria using the Newton divided interpolation method has revealed vital information. Findings from this study have shown, that the prediction model used in this study showed high level of accuracy as the values of the prediction function were almost the same as the data points captured at the site with negligible estimated errors. This was evident from the overlapping graphs for instance, at the traffic light, 115.5W/m^2 (115.5J/m^2) was recorded at about 10:00 hours, the modeled result revealed 115.5137W/m^2 (115.513J/m^2) which produced a marginal error of 0.0137. Similarly, the same marginal errors were recorded from the hours of 10:00 to 4:00 throughout the study due to high level of accuracy of the prediction model. The peak hour of solar intensity at the construction site was at 2:00 hours. The irradiance was recorded to be 205.00W/m^2 (205.00J/m^2) while the prediction was 204.9957W/m^2 (204.9957J/m^2) with a negligible error of 0.0043. This clearly shows that the prediction can be sufficiently used at any solar hour. This finding is quite different with that of Adeniji *et al.* [15] who estimated global solar radiation, sunshine hour distribution and clearness index using Gunn Bellani Radiometer and Angstrom-type correlation in Nugu, Nigeria.

Findings from this study have also shown that the mean irradiant value at the traffic light was 179.1W/m^2 (179.1J/m^2) with erythema effective irradiance 227.3W/m^2 (227.3J/m^2) occurring at 13:00 hours which is 1.14 minimum erythema dose (MED)/hr, while the predicted mean value was 179.1±0.025W/m^2 (179.1±0.025J/m^2). Also, the mean irradiant value at the construction site was 173.53W/m^2 (173.53J/m^2) with erythema effective irradiance 205W/m^2 (205J/m^2) occurring at 14:00 hours which is 1.03 MED/hr, while the predicted mean value was 172.8±0.004W/m^2 (172.8±0.004J/m^2). These values are way higher than the ICNIRP recommended safety limit of 30J/m^2 for occupational exposure as stated in Vecchia *et al.* [16]. UV index was 8 for construction site and 9 for traffic light, indicating very high risk of harm from unprotected sun exposure. This implies that the occupational workers carrying out outdoor activities especially traffic wardens and construction workers around Makurdi Metropolis are been over exposed to UVR which with time, they may experience photo-conjunctivitis, skin cancer, cortical cataract, photo-ageing, carcinoma of cornea, and immune depression among others. This finding is in line with that of Parisi *et al.* [17] who determine solar erythema UVR exposures to the skin through common summer garments during outdoor activities and obtained 1.7 MED/hr using polysulphone dosimeters in Australia. Also, the findings is in line with the findings of Kimlin *et al.* [18] who worked on anatomical distribution of solar UVR exposures among cyclists and obtained 0.94 MED for the ankle, 1.28 MED for back of the hand, 1.14 MED for side of the head, and 1.80 MED for the head top using polymer polysulphone dosimeters in Queensland, Australia. The findings are also well compared with that of Igbawua *et al.* [6] who determined the average solar UV radiation dosimetry and obtained a mean value of 432±47J/m^2 using UVR- meter and Polymer Polysulphone dosimeters at Gboko, Central Market Benue State. The findings in this study are not in line with that of Weber *et al.* [19] who worked on Solar UVR exposure of outdoor workers and obtained an erythema radiant exposure of 2700J/m^2 which is 13.5 MED for skin type 1 using UVR-sensitive polysulphone (PS) film badges and electronic UV dosimeters in Austria. Also, this finding is not in line with that of Wolska [7] who worked on occupational exposure to solar ultraviolet radiation of polish outdoor worker and the result exceeded 10 standard erythema doses using risk estimation method and criterion. The finding is also not in line with those obtained by Cockell *et al.* [20] who determined a (70S; 80W) field scientist's erythema UVR exposure in the Arctic using biological UVR dosimeters that uses B. Subtilisbio film and 5.8 standard erythema dose (SED) compared to 14.4 SED for a horizontal surface.

5. CONCLUSION

The use of Newton Divided Interpolation Method have shown high level of accuracy for the predicted values. This is evidence as there is no significant difference between the measured irradiance values and the predicted values for both construction site and traffic light areas. However, the results of this research have shown that the mean outdoor UVR levels in Makurdi metropolis are above the ICNIRP recommended safety limit for occupational exposure of $30J/m^2$ as stated in Vecchia *et al.* [16]. The erythema radiant exposures were measured and consequently the MED for skin type I (MED = $200J/m^2$) was exceeded by a factor of 1. Exposure to high outdoor UVR can lead to Erythema effects which is basically seen as the redness of the skin due to sunburn which is premised by over exposure to solar radiation. Therefore, traffic warden and construction workers around Makurdi Metropolis should avoid outdoor activities at high sunshine hours (13:00 hours to 14:00 hours) and wear protective clothing so as to avoid over exposure to UVR that could cause severe harmful effects.

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